Space Technology Research Grants

Diamond Electron-Spin Clocks For Space Navigation and Communication

Completed Technology Project (2012 - 2016)

Project Introduction

Precision clocks are needed in a broad range of applications, including satellite communication, high-bandwidth wireless communication, computing systems, and navigation, such as the global positioning system (GPS). The most accurate time and frequency standards developed to date are atomic clocks, which derive their stability from electronic transitions in atoms. But atomic clocks, which rely on atomic gases or trapped ions and atoms, are large and difficult to assemble and control. By contrast, a solid-state alternative leveraging modern semiconductor technology would be ideal for integration in a range of devices, may be orders of magnitude smaller, lighter, and be more durable in a range of potentially harsh environments. The material hardness, rigidity, and compactness of the proposed solid-state atomic clock analog makes it ideal for space applications. In particular, in this program, we propose to develop a solid-state alternative to atomic clocks, implementing our recent theoretical proposal for frequency locking to magnetic sub-levels of the nitrogen vacancy (NV) color center in diamond. Due to the NVs exceptionally long spin coherence time, a high density of spins in the solid, and optical spin detection, we estimate a time stability that rivals or exceeds the performance of the newest chip-scale Cs and Rb standards, but in a package that is at least 2 orders of magnitude smaller and lighter. Developing an atom-like standard in a solid state host promises rapid integration into semi-conductor fabrication processes, thus achieving a technological breakthrough in portable standards. The goal of the proposed program is to (i) develop a diamond-based, 2.87-GHz CMOS-integrated clock employing electronic transitions in ensembles of the diamond NV center, and to reach an Allan deviation better than 10^12/(integration_time)^1/2, matching or exceeding the performance of compact atomic clocks; and (ii) to establish a full quantum-theoretic understanding of spin-based frequency and time standards based on color centers in diamond, promising advanced spin clock protocols. Solid-state implementations of high- performance atomic gyroscopes and atomic magnetic gradiometers will be investigated. This solid-state alternative to atomic clocks could benefit a range of NASA capabilities: smaller, lower-power clocks in satellites; uninterruptable/jam-tolerant GPS navigation; compact satellites; formation flying; deep-space space-craft; and micro-satellites. The program would also advance our theoretical understanding of possible high-performance gyroscopes for navigation and magnetic gradiometers for magnetic imaging at security checks or in the field.

Anticipated Benefits

This solid-state alternative to atomic clocks could benefit a range of NASA capabilities: smaller, lower-power clocks in satellites; uninterruptable/jam-tolerant GPS navigation; compact satellites; formation flying; deep-space space-craft; and micro-satellites. The program would also advance our theoretical understanding of possible high-performance gyroscopes for navigation and magnetic gradiometers for magnetic imaging at security checks

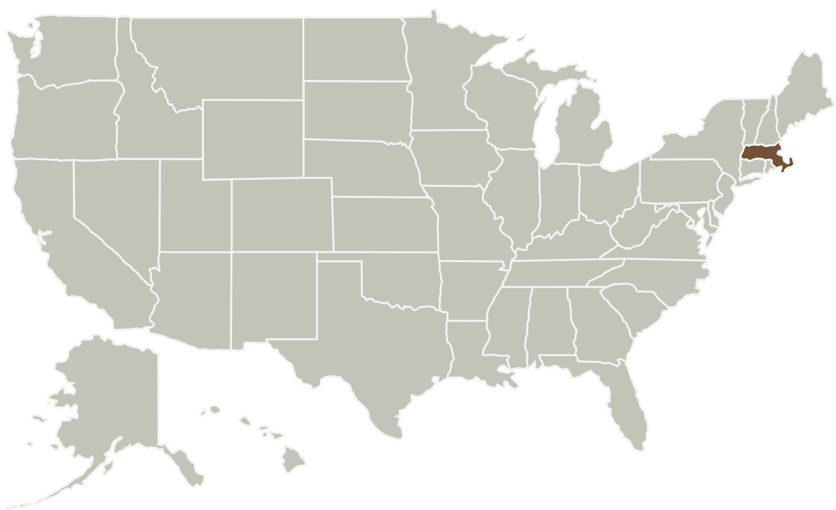
Project Image Diamond Electron-Spin Clocks For Space Navigation and Communication

Table of Contents

Project Introduction	1
Anticipated Benefits	1
Primary U.S. Work Locations and Key Partners	2
Organizational Responsibility	2
Project Management	2
Images	3
Project Website:	3
Technology Maturity (TRL)	3
Technology Areas	3
Target Destinations	3

or in the field.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
Massachusetts Institute of Technology(MIT)	Lead Organization	Academia	Cambridge, Massachusetts

Primary U.S. Work Locations
Massachusetts

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

Massachusetts Institute of Technology (MIT)

Responsible Program:

Space Technology Research Grants

Project Management

Program Director:

Claudia M Meyer

Program Manager:

Hung D Nguyen

Principal Investigator:

Dirk Englund

Co-Investigator:

Hannah A Clevenson

Images

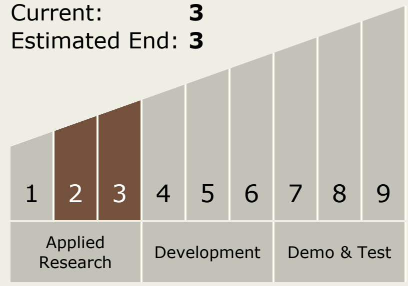
11485-1363183249913.jpg
Project Image Diamond Electron-Spin Clocks For Space Navigation and Communication
(https://techport.nasa.gov/image/1758)

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html

Technology Maturity (TRL)

Start: **2**
Current: **3**
Estimated End: **3**



Technology Areas

Primary:

- TX05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems
  └ TX05.4 Network Provided Position, Navigation, and Timing
    └ TX05.4.1 Timekeeping and Time Distribution

Target Destinations

Earth, Others Inside the Solar System